

Substitute  
Specification

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1 TITLE

2 Al/Cu/Mg/Ag alloy with Si, semi-finished product from such an  
3 alloy as well as method for the production of such a semi-  
4 finished product

5

6 CROSS REFERENCE APPLICATIONS

7 This application is a national phase application  
8 claiming priority from PCT application no. PCT/EP2002/07193  
9 filed on 29 June 2002.

10

11 FIELD OF INVENTION

12 Subject matter of the invention is an Al/Cu/Mg/Mn alloy  
13 for the production of semi-finished products with high static  
14 and dynamic strength properties. The invention further  
15 relates to semi-finished products manufactured from such an  
16 alloy with high static and dynamic strength properties as  
17 well as to a method for the production of such a semi-  
18 finished product.

19

20 BACKGROUND OF THE INVENTION

21 Aluminum alloys having a high static and dynamic bearing  
22 capacity include the alloys AA 2014 and AA 2214. Drop-  
23 forged parts for wheel and brake systems of airplanes are  
24 manufactured from these Al alloys in the artificially aged  
25 state. The semi-finished products produced from the alloy  
26 intrinsically have the listed strength properties of the  
27 alloys, especially at lower temperatures. However, at  
28 temperatures of more than 100° C these properties decrease  
29 more rapidly than is the case with alloys of the group AA  
30 2618.

1       Semi-finished products of the alloys of group AA 2618  
2       have better high-temperature stability and are utilized for a  
3       variety of uses such as compressor impellers for rechargeable  
4       diesel engines or for rotors of ultracentrifuges. However,  
5       at temperatures below 100°C, the aluminum alloys of the group  
6       AA 2014 and AA 2214 have greater bearing capacity.

7       In the wheel brake system of airplanes considerable heat  
8       is generated during the braking process. This leads to  
9       temperature increases even in the wheels, which typically are  
10      fabricated of an AA 2014 or AA 2214 alloy. These can cause  
11      early overageing of this alloy and lead to a severe  
12      limitation of the service life of the structural part.

13      In compressor impellers the transition to titanium  
14      alloys has been made to give the compressor impellers the  
15      necessary static and dynamic strength properties even at  
16      increased temperatures. However, employing titanium is  
17      expensive is therefore not suitable for the production of  
18      airplane wheels. Furthermore, titanium is less well suited  
19      as a material for wheels due to its limited thermal  
20      conductivity, .

21      The problematic described above is not new. Therefore,  
22      for many years there has been the wish for an Al alloy, which  
23      combines the high strength properties of the alloys AA 2014  
24      or AA 2214 at ambient temperature and the thermal stability  
25      of the alloys AA 2618 or 2618 A.

## 26                                   **SUMMARY OF THE INVENTION**

27      The invention therefore addresses the problem of  
28      providing such an alloy, a semi-finished product produced of  
29      such an alloy with high static and dynamic bearing capacity,  
30      high thermal stability, high fracture toughness and high

1 creep resistance as well as a method for the production of  
2 such semi-finished products.

3

4 Other aspects of this invention will appear from the  
5 following description and appended claims, reference being  
6 made to the accompanying drawings forming a part of this  
7 specification wherein like reference characters designate  
8 corresponding parts in the several views.

9 This problem is solved according to the invention with  
10 an alloy that has the following composition:

11 0.3 - 0.7 wt. % silicon (Si)  
12 maximally 0.15 wt. % iron (Fe)  
13 3.5 - 4.5 wt. % copper (Cu)  
14 0.1 - 0.5 wt. % manganese (Mn)  
15 0.3 - 0.8 wt. % magnesium (Mg)  
16 0.05 - 0.15 wt. % titanium (Ti)  
17 0.1 - 0.25 wt. % zirconium (Zr)  
18 0.3 - 0.7 wt. % silver (Ag)  
19 maximally 0.05 wt. % other, individually  
20 maximally 0.15 wt. % other, total  
21 remaining wt. % aluminum (Al).

22

23 Compared to the prior known alloys AA 2014 and AA 2214,  
24 the claimed alloy has higher static and dynamic thermal  
25 stability and improved creep resistance while also having  
26 very good mechanical fracturing properties. These properities  
27 are attained in particular at a copper-magnesium ratio  
28 between 5 and 9.5, in particular at a ratio between 6.3 and  
29 9.3. The copper content is preferably between 3.8 and 4.2  
30 wt. % and the magnesium content between 0.45 and 0.6 wt. %.  
31 The copper content is markedly below the maximum solubility

1 for copper in the presence of the claimed magnesium content.  
2 As a consequence, the fraction of insoluble copper-containing  
3 phases is very low, also taking into consideration the  
4 remaining alloy and companion elements. Thereby an  
5 improvement is obtained with respect to the dynamic  
6 properties and the fracture toughness of the semi-finished  
7 products manufactured from such an alloy.

8 In contrast to the known AA alloys 2014 and 2219, a  
9 portion of the claimed alloy is silver with contents between  
10 0.3 and 0.7 wt. %, preferably 0.45 and 0.6 wt. %. In the  
11 interaction with silicon (0.3 - 0.7 wt. %, preferably 0.4 -  
12 0.6 wt. %) the hardening takes place via the same mechanisms  
13 as in silver-free Al/Cu/Mg alloys. However, it has been  
14 found that with lower silicon contents, the course of  
15 precipitation is different due to the addition of silver.

16 While the semi-finished products manufactured from such  
17 an alloy have good high-temperature stability and creep  
18 resistances under cooler conditions, they do not meet the  
19 desired requirements. Only silicon contents above 0.3 wt. %  
20 suppress the otherwise typical change of the precipitation  
21 behavior of Al/Cu/Mg/Ag alloys, such that unexpectedly higher  
22 strength values can be attained without having to give up the  
23 high-temperature stability and the creep resistance with the  
24 Cu and Mg contents according to the invention.

25 The manganese content of the claimed alloy is 0.1 to 0.5  
26 wt. %, preferably 0.2 - 0.4 wt. %. In the case of alloys  
27 with higher manganese contents undesirable precipitation  
28 processes were found with long-term high-temperature stress,  
29 which led to a decrease of strength. For this reason the  
30 manganese content is limited to 0.4 wt. %. However,

1 manganese is fundamentally required as an alloy component for  
2 the control of the grain structure.

3 To balance the reducing effect of manganese with respect  
4 to the grain structure control, the alloy contains zirconium  
5 between 0.10 - 0.25 wt. %, preferably 0.14 - 0.20 wt. %. The  
6 precipitating zirconium aluminides, as a rule, are developed  
7 even more finely dispersed than manganese aluminides.  
8 Moreover, it was found that the zirconium aluminides  
9 contribute to the thermal stability of the alloy.

10 For grain sizing 0.05 - 0.15 wt. %, preferably 0.10 -  
11 0.15 wt. % of titanium is added. The titanium is usefully  
12 added in the form of an Al/5Ti/1B prealloy, whereby boron is  
13 automatically included in the alloy. Finely dispersed,  
14 insoluble titanium diborides are formed therefrom. These  
15 contribute to the thermal stability of the alloy.

16 The alloy can comprise maximally 0.15 % iron, preferably  
17 0.10%, as an unavoidable contamination.

18

#### 19 BRIEF DESCRIPTION OF THE DRAWINGS

20

21 Fig. 1 is a graph showing the 0.2% yield strength and the  
22 tensile strength of the alloy according to the  
23 invention in state T6 in comparison to prior known  
24 alloys, as a function of the test temperature.

25

26 Fig. 2 is a graph showing the long-time stress to rupture  
27 strength of the alloy according to the invention in  
28 state T6 in comparison to known alloys.

29

30 Fig. 3 is a graph showing the 0.2% yield strength and the  
31 tensile strength of airplane wheels manufactured from

1           the alloy according to the invention in comparison to  
2           such manufactured from known alloys.

3  
4   Figs. 4a and 4b are graphs showing the fatigue strength of  
5           the alloy according to the invention in comparison to  
6           a known alloy in state T6 at ambient temperature and  
7           at a temperature of 200° C.

8  
9           Before explaining the disclosed embodiment of the  
10   present invention in detail, it is to be understood that the  
11   invention is not limited in its application to the details of  
12   the particular arrangement shown, since the invention is  
13   capable of other embodiments. Also, the terminology used  
14   herein is for the purpose of description and not of  
15   limitation.

#### 16 17                   **DETAILED DESCRIPTION OF THE INVENTION**

18           Table 1 reproduced below shows the chemical composition  
19   of four alloys (B, C, D, E) according to the invention as  
20   well as the composition of the alloys AA 2214 and AA 2618  
21   examined as a comparison (data in wt. % (n.d.: not  
22   determined)

1   **Table 1**

2

Alloy	Si	Fe	Cu	Mn	Mg	Ni	Zn	Ti	Ag	Zr	V
B	0.47	0.08	4.40	0.200	0.58	0.003	0.048	0.135	0.45	0.150	0.018
C	0.47	0.08	3.64	0.210	0.59	0.003	0.015	0.115	0.52	0.150	0.017
D	0.47	0.08	3.87	0.200	0.61	0.003	0.015	0.117	0.52	0.150	0.019
E	0.52	0.08	4.14	0.200	0.61	0.003	0.02	0.115	0.44	0.150	0.018
AA 2214	0.77	0.17	4.29	0.883	0.57	0.003	0.031	0.024	0.003	0.007	n.d.
AA 2618	0.22	1.1	2.58	0.020	1.53	1.007	0.043	0.059	0.003	0.002	n.d.

3

4   From these alloys semi-finished products were manufactured  
5   following the method steps listed below:

6   a)   casting of an ingot from an alloy,

7   b)   homogenizing the cast ingot at a temperature, which is as  
8   close under the incipient melting temperature of the alloy as  
9   is possible, for a length of time adequate to attain

10   maximally uniform distribution of the alloy elements in the  
11   cast structure,

12   c)   hot working of the homogenized ingot by forging at a  
13   block temperature of approximately 420°C,

14   d)   solution treatment of the semi-finished product worked by  
15   forging at temperatures sufficiently high to bring the alloy  
16   elements necessary for the hardening into solution such that  
17   they are uniformly distributed in the structure, with the  
18   solution treatment taking place in a temperature range of  
19   505°C over a time period of 3 hours,

1 e) quenching of the solution-treated semi-finished product  
2 in water at ambient temperature,  
3 f) cold working of the quenched semi-finished products by  
4 cold upsetting by 1 to 2%, and  
5 g) artificial ageing of the quenched semi-finished product  
6 at a temperature of 170°C over time period of 20 to 25 hours.  
7 The open-die forged pieces produced in this manner were  
8 subsequently tested for their properties in the artificially  
9 aged state T6.

10 **Table 2**

11 **Strength values at ambient temperature**

**Fracture toughness at ambient temp.**

Alloy	Sample direction	R <sub>p02</sub> (MPa)	R <sub>m</sub> (MPa)	A <sub>5</sub> (%)	Sample direction	K <sub>IC</sub> (MPa√m)
C	L	448	485	11.2	T-L	31.3
	LT	427	471	7.2	S-L	29.5
	ST	417	479	6.3	S-T	32.2
D	L	456	495	10.7	T-L	28.3
	LT	434	478	8.0	S-L	29.1
	ST	429	484	5.5	S-T	29.6
E	L	454	494	9.9	T-L	26.1
	LT	446	493	6.4	S-L	25.5
	ST	438	494	4.9	S-T	26.9
AA 2214	L	444	489	9.7	T-L	24.2
	LT	439	483	6.4	S-L	25.9
	ST	429	480	5.8	S-T	27.3
AA 2219	L	286	408	16.7	T-L	31.1
	LT	288	403	8.4	S-L	34.4
	ST	366	455	5.0	S-T	32.3
AA 2618	L	389	443	5.1	T-L	19.2
	LT	383	437	4.7	S-L	16.7
	ST	376	427	4.1	S-T	19.3

12

13

14



1 **Table 3**

2

<b>Alloy</b>		<b>E</b>			<b>AA 2214</b>			<b>AA 2618</b>		
$R_{test}$ (°C)	$T_{hold}$ (h)	$R_{p0.2}$ (Mpa)	$R_m$ (Mpa)	$A_5$ (%)	$R_{p0.2}$ (Mpa)	$R_m$ (Mpa)	$A_5$ (%)	$R_{p0.2}$ (Mpa)	$R_m$ (Mpa)	$A_5$ (%)
20	1	454	494	9.9	444	489	9.6	380	434	6.5
50	1	453	493	12.6	443	485	9.8	382	433	6.1
100	1	449	474	13	425	458	11	374	423	6.5
150	1	404	417	14.3	403	424	13.6	366	404	7.6
170	1	403	416	16.3	382	400	13.6	382	389	9.6
200	1	355	372	18	348	368	13.8	340	359	12.2
220	1	340	351	18	324	344	14.2	301	332	12.4
250	1	268	282	19	250	268	16.1	282	300	14.7

3

4 Definitions sample directions:

5 L= longitudinal direction: parallel to the main form change direction

6 LT= long transverse direction: parallel to the width direction

7 ST= short transverse direction: parallel to the thickness direction

8

9       The improved strengths of the alloy according to the  
10 invention (for example alloy E) is clearly evident in Tables  
11 2 and 3. For example, while the prior known alloy AA 2214  
12 shows good strength values at ambient temperature, it does  
13 not at higher temperatures. Moreover, the creep resistance  
14 and the fracture toughness are markedly better at ambient  
15 temperature and at higher temperatures in the claimed alloy  
16 compared to the prior known alloys. This comparison makes  
17 clear that the tested prior known alloys have good properties  
18 only with respect to a single strength parameter. In no case  
19 do the prior alloys have good properties in all relevant

1 strength values at ambient temperature as well as at  
 2 increased temperatures. Just as is the case with the fatigue  
 3 properties, the creep resistance of this prior known alloy is  
 4 not satisfactory. Very good properties over all tested  
 5 strength parameters could only be determined in the case of  
 6 the alloy according to the invention.

7 Figure 1 also makes graphically clear the better  
 8 strength properties of the alloy (alloy E) according to the  
 9 invention compared to the known alloys (AA 2214 as well as AA  
 10 2618). The results showed unexpectedly that the strength  
 11 values of alloy E are better even at temperatures below 100°C  
 12 than those of the known alloy AA 2214, which is known for its  
 13 especially high strength values in this temperature range.

14 Additionally, the creep resistance of the semi-finished  
 15 products was tested. Table 4 shown below provides the test  
 16 results (LMP: Larson Miller parameter) in summary:

17

18 **Table 4:**

<b>Alloy</b>											
<b>E</b>				<b>AA 2214</b>				<b>AA 2618</b>			
<b>T<sub>test</sub></b> <b>(°C)</b>	<b>σ<sub>test</sub></b> <b>(MPa)</b>	<b>t<sub>fracture</sub></b> <b>(h)</b>	<b>LMP</b> <b>(-)</b>	<b>T<sub>test</sub></b> <b>(°C)</b>	<b>σ<sub>test</sub></b> <b>(MPa)</b>	<b>t<sub>fracture</sub></b> <b>(h)</b>	<b>LMP</b> <b>(-)</b>	<b>T<sub>test</sub></b> <b>(°C)</b>	<b>σ<sub>test</sub></b> <b>(MPa)</b>	<b>t<sub>fracture</sub></b> <b>(h)</b>	<b>LMP</b> <b>(-)</b>
180	185	2513	10.60	205	200	30	10.27	205	183	10	10.04
	167	4762	10.82		190	50	10.38		179	50	10.38
					181	100	10.52		175	100	10.52
					130	500	10.85		163	500	10.85
					100	800	10.95		159	1000	11.00

19

20 Plotted graphically, the markedly better long-time stress to  
 21 rupture strength of the alloy in the T6 state in comparison

1 to the known alloys AA 2214 and AA 2618 in the T6 state is  
2 apparent. This is shown in Figure 2 as time-compensated  
3 temperature representation. The especially good creep  
4 resistance of the alloy according to the invention could not  
5 be foreseen making this result surprising.

6 Within the scope of testing the method steps for the  
7 production of these semi-finished products, it was found that  
8 comparable material properties of the produced semi-finished  
9 products can be attained if the step of hot working is  
10 carried out at a block temperature between 320°C to 460°C.  
11 The hot working can be either forging or rolling. The step  
12 of quenching of the solution treated semi-finished product  
13 can take place in a temperature range between ambient  
14 temperature and 100°C (boiling) in water. It is also  
15 possible to utilize a water-glycol mixture for the quenching,  
16 the temperature of which- should not exceed 50°C.

17 A cold working step of a drawing out by 1% to 5% can be  
18 carried out in the case of extruded or rolled products for  
19 the purpose of reducing the intrinsic stresses due to the  
20 quenching instead of the previously described step of cold  
21 working through cold upsetting during forging. The step of  
22 artificial ageing can be carried out over a time period of 5  
23 to 35 hours, preferably between 10 and 25 hours, in a  
24 temperature window between 170°C and 210 °C.

25 During further tests strand-cast ingots were produced as  
26 described above and airplane wheels manufactured by drop  
27 forging in the preforge die and finish forge die at a  
28 temperature of 410 to 430°C. These wheels were subsequently  
29 solution treated at 505°C, quenched in a mixture of water and  
30 glycol of ambient temperature and thermally age-hardened at  
31 170°C for 20 hours. These were compared to mass-produced

1 airplane wheels of the alloy AA 2214. Samples were taken  
2 from the wheels produced of the claimed alloy and of the  
3 conventional alloy at sites distributed over the  
4 circumference, and tested for their tensile strength. The  
5 results are shown in Figure 3. It can clearly be seen that  
6 the alloy E according to the invention yields better values  
7 compared to the known alloy AA 2214.

8 Fatigue tests in comparable samples of the two cited  
9 alloys also show that the wheels produced from the claimed  
10 alloy attain markedly better values than the wheels produced  
11 from the alloy AA 2214. This applies to the fatigue tests  
12 carried out at ambient temperature (cf. Figure 4a) as well as  
13 to the fatigue tests carried out at a test temperature of  
14 200°C (cf. Figure 4b).

15 The description of the claimed invention makes clear  
16 that surprisingly the claimed alloys have not only high  
17 dynamic and static strength values, but that they have an  
18 especially good high-temperature stability, fracture  
19 toughness and creep resistance. This alloy is therefore  
20 particularly suitable for the production of semi-finished  
21 products, which must meet precisely these requirements, such  
22 as airplane wheels or compressors.

23 Although the present invention has been described with  
24 reference to the disclosed embodiments, numerous  
25 modifications and variations can be made and still the result  
26 will come within the scope of the invention. No limitation  
27 with respect to the specific embodiments disclosed herein is  
28 intended or should be inferred. Each apparatus embodiment  
29 described herein has numerous equivalents.

30